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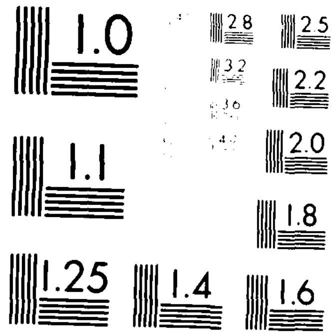

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Manufacturing Methods and Technology

COMPUTERIZED PRODUCTION PROCESS PLANNING

VOLUME II BENEFIT ANALYSIS

AD-A151 996

Interim Report

November, 1976

Hsien-Hwei H. Shu
Janis C. Church
Jack P. Kornfeld

U.S. Army Missile Command
Contract No. DAAH01-76-C-1104

Prepared by: IIT Research Institute
Chicago, Illinois 60616

For: United Technologies Research Center
East Hartford, Ct 06108

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Process planning methods and associated costs are discussed. A preliminary analysis of the benefits of computerized production process planning is presented and discussed.

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Borg-Warner Corp.
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SUMMARY

This report contains the results of a cost benefit analysis of various levels of computerized production process planning for cylindrical and non-cylindrical machined parts. The results of the study indicate that:

- Computer aided process planning can significantly lower the costs of manufacturing machined parts.

- That computer aided process planning can have a major impact on numerous other factors influencing overall manufacturing productivity.

- The vast majority of the companies contacted are receptive to computer aided planning and are either currently using or plan to use such techniques in the near future.

- The economic viability of a particular level of process planning automation depends primarily on the indigenous circumstances of individual companies, particularly with respect to product similarity and annual sales volumes.

- The more simplistic approaches to computer aided process planning offer better short-term economic payoff; however, the more sophisticated approaches offer greater potential lowering costs and increasing productivity in the long run.

Missile Prime and Subcontractors	4
Other Aerospace Companies	8
Other Types of Manufacturers	9
	21

Because of the large amount of data received (each data request had approximately 330 possible entries), the approach used to analyze the data was to develop a detailed spread sheet on which to transfer the data for subsequent analysis. Compounding the magnitude of the task was the fact that the data request was structured in such a manner as to facilitate numerous intermediate calculations for additional analysis and cross checks to assess the validity of the data received. Needless to say, the spread sheet turned out to be quite large; however this also turned out to be an advantage during the analysis because it displayed all of the data and calculations in a way that variations between responses could be easily assessed visually.

Once the information had been transferred to the spread sheet and the intermediate calculations had been made, each entry and calculation was rechecked to insure accuracy. Following this, the data was entered into a computer for further analysis.

Specifically, for each column of data the means, standard deviations, minimum observations, maximum observations and number of responses was computed. This was done for each of the three industry categories and the total of all responses received. Additionally, histograms were plotted for each data column and industry grouping. The results of these analyses are contained in Appendices B and C.

also is capable of generating a feasible, efficient process plan by using internally stored data and logic.

The data request was mailed to 153 individuals in various manufacturing companies and divisions. The identification of individuals who would be mailed requests was <u>not</u> random; the criteria used in selecting the addressees were that each Army missile prime contractor should receive a data request and individuals known to be knowledgeable in the subject matter should also be solicited for information.

A breakdown of the mailing by industry type is as follows:

Missile Prime and Subcontractors	14
Other Aerospace Companies	37
Other Types of Manufacturers	102
TOTAL	153

Twenty-one responses were received from the mailing, although all questions were not answered by every respondee. This represents a response rate of 13.7%, an unusually high number for a survey of this type and breadth.

The analysis of the data received is summarized in the next section.

2.2 Data Analysis

As mentioned previously, 21 data requests were returned for analysis. By industry type, the responses were as follows:

2. In operation of the system, a process planner would sit down at a CRT terminal and input data on the machined part design (e.g., geometry, tolerances, surface finish, hardness, concentricity, etc.), the starting material (e.g., type, geometry, etc.) and the lot size. The computer system would then generate a process plan using the process decision rules to select the machine or equipment type, select tooling and fixtures, and determine optimum machine/tool path combinations for each metal removal operation. The system also calculates time standards, inserts operations for heat treating, cleaning, inspection, etc., and produces sketches of the workpiece and tooling suitable for inclusion in the operation sheets. The process planner can interact with the system if he wishes to override the decision logic and specify details of a particular operation or if the data bases are incomplete and the system needs inputs from him to proceed. The final process plan, including routing sheets and detailed operation sheets is then stored in the data base for future use.

3. A process planner can also use the system to retrieve and to modify process plans which have been previously generated and stored in the data base.

In summary, at this level of automation, the computer may be used not only for the retrieval and up-dating of existing process plans, but

enabling the system to produce most or all of the process planning without relying on the existence of a standard process plan or a process plan for a similar part (although this system could also operate in the same mode as System 2).

The main features of this system are described below:

1. The system has the following data bases:

   a) A machine/equipment data base which contains information concerning a machine's physical characteristics, cutting capabilities, tolerance ratings and operating costs.

   b) A tooling data base which contains information on tool geometry, material, application and cost.

   c) A machinability data base which contains information on speeds, feeds, tool life, etc. This data base has two parts, one for "look-up" data on machinability, and one for machinability equations which are used to optimize processing parameters.

   d) A data base containing process decision rules which provide the system with the logic needed to generate process plans. In general, these rules would be developed from past experience in a particular plant.

   e) Stored process plans for previously planned parts.

Such determination may be through either a table look-up in a machinability database or an analysis of empirical equations for metal removal. These parameter values, as well as other processing parameter values (e.g., heat treating temperature and time, etc.), may be reviewed by the process planner and modified if desired.

4. The completed process plan is then stored in the database under its part number for future reference.

5. The computer is used in the generation of shop documents as described in System 1.

At this level of automation, the computer is used to (a) assist in retrieving process plans that are closely related to the part in question; (b) facilitate interactive editing (modifying and enriching) the retrieved process plan; (c) determine best metal cutting parameters and associated time; and (d) produce needed documents for shop use (excluding sketches, which must still be prepared manually).

System 3

Semi-Automatic System with Computer-Aided Operation Determination

This system is considerably different from the previous systems in several respects. One of the major differences is that this system has a "generative" process planning capability in that it contains a certain degree of decision logic concerning process planning, thereby

1. A computerized database in conjunction with appropriate database management software will allow the retrieval of:

   a) A list of parts belonging to the same part family (i.e., a list of all parts having the same Group Technology code).

   b) A skeletal (or standard) sequence of operations for a particular Group Technology code.

   c) A process plan for an existing part number.

2. An interactive graphics (CRT terminal) capability to enhance a skeletal sequence of operations retrieved by a Group Technology code or modify an existing process plan for a particular part number. The editing consists of:

   a) Entering or modifying production demand data (e.g., job no., lot size, etc.)

   b) Deleting and adding operation and associated data on a routine sheet.

   c) Detailed planning for any operation on an oper ation sheet.

3. The edited results are the inputs to cutting parameter determination subroutines. Typically, the best feeds of a material removal operation with know machine and tooling will be determined and the associated cutting time computed.

coded into the computer (by keypunch operators working from a coding sheet) which, in turn, produces hard copy documents for the shop. These documents may be:

a) Routing sheets containing a summary of the operations, machines and equipment needed. jigs/fixtures and cutter types, and standard times for each operation,

b) Operation sheets contained detailed instructions for each operation such as cutter path feeds, speeds and/or material processing parameters. If graphical aids are needed for these operations, these aids are manually generated.

At this level of automation, therefore, the process planner is (a) assisted in locating a process plan that is closely related to the part in question if such a plan exists and (b) relieved of much of the tedium of producing documents used in the production of the part.

System 2

Interactive System with Computer-Aided Cutting Parameter Determination

This system is essentially the same as System 1 except that it has been up-graded in the following areas:

System 1

Computer-Aided Group Technology Code Management and Document Generation

At this level of automation, the process planner does essentially what he used to do manually except in two respects:

1. Every machined part, distinguishable by its part number, is also assigned a Group Technology Code which classifies the geometry and machining requirements of various machined parts into part families. A process planner assigns a code to a given part by inspection of the blueprint. Computer maintained Group Technology code data files, in the form of listings, are then examined to ascertain whether the process plan of a given part: a) is currently available; b) can be prepared by modifying an existing process plan for a similar part; or c) must be created from scratch because the part belongs to none of the know part families. The planner will then take advantage of the information uncovered in his manual effort to produce a process plan for the part. The Group Technology code data files are up-dated periodically to reflect current availability of similar process plans.

2. Once the process plan of a given part is manually prepared, the machining and material process steps are:

in that very litte concrete data concerning the economics of CPPP was uncovered; however, it did prove beneficial in terms of providing information on intangible benefits, current levels of usage of CPPP and potential roadblocks to implementing such systems. The individual contacts also proved helpful from the standpoint of providing data and clarification and consultation during the analysis phase.

However, the source of information which proved to be most fruitful was the data request. A copy of the data request is contained in Appendix A.

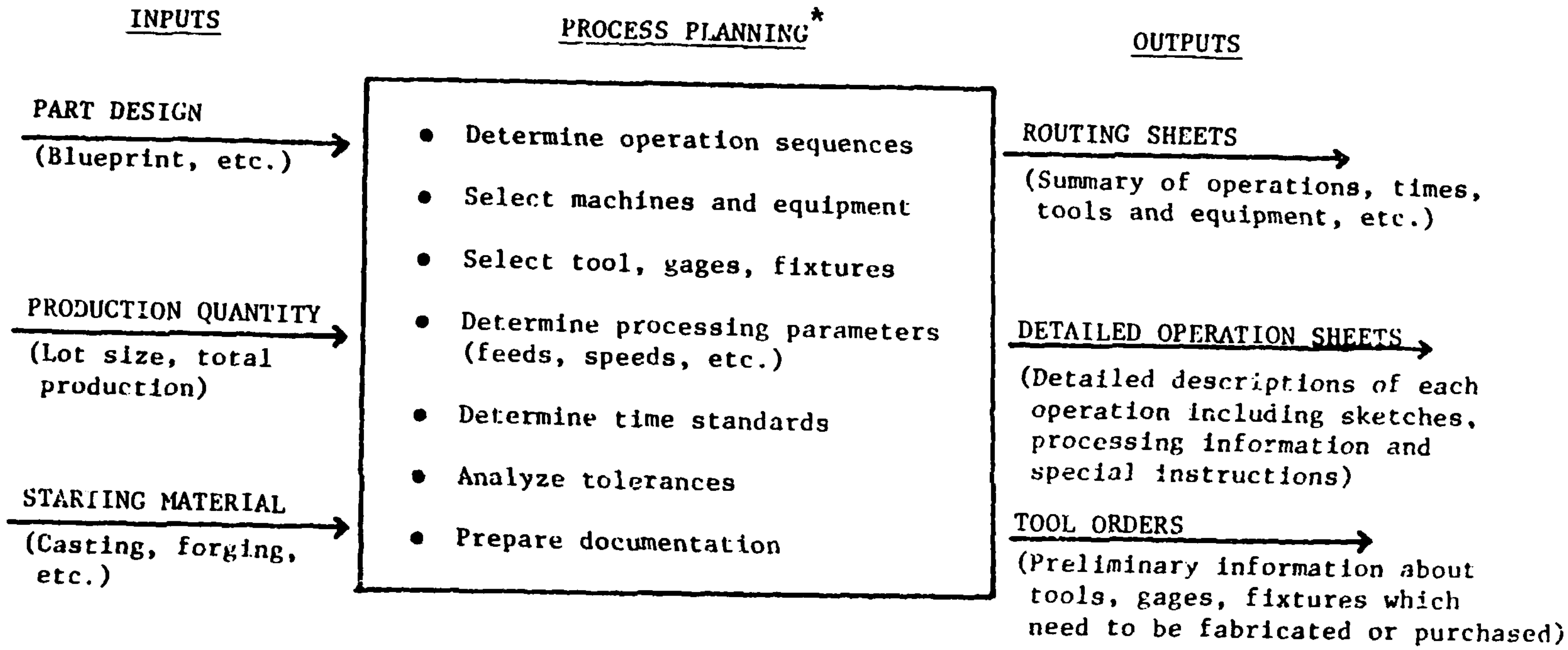
The data request consisted of three major sections. The first section described the purpose of the request and provided definitions needed to complete the form. The second section requested information which would characterize the company, its products, and other relevant parameters--process planning methods and costs, current and planned usage of CPPP, machining costs, tooling costs, etc. In the third section, three different levels of process planning automation, or CPPP systems, were described and each addressee was asked to estimate the benefits over manual process planning, implementation costs, operation and maintenance costs, and obstacles to implementing each system.

The three CPPP systems contained in the data request are described below. System 3 is the most similar to the CPPP system being developed in this program.

- Determination of operations and sequences.
- Selection of machines and equipment needed to perform the operations.
- Selection of appropriate tools, gages, and fixtures.
- Determination of process parameters, speeds, feeds, cutter paths, etc.) for each operation.
- Determination of time standards.
- Analysis of tolerances.
- Preparation of routing sheets which summarize the operations to be performed, the times required for each operation and the tooling and equipment needed.
- Preparation of detailed operation sheets which describe each operation, including sketches of the workpiece, identification of tools, fixtures, etc., tool layout and parts clamping, speeds and feeds, and special instructions for inspection, cleaning, etc.
- Preparation of tool orders for jigs, fixtures, gages, etc., which need to be fabricated or purchased.

Process planning, as we have defined it, does <u>not</u> include production scheduling, tool design, NC part programming or plant layout.

The primary methods used to collect data were literature searches, contacts with individuals knowledgeable in the area and a data request which was mailed to numerous companies. The literature search proved disappointing



* As defined here, process planning does not include NC part programming, production scheduling, planning and scheduling of material handling, tool design or plant layout.

Figure 1. DIAGRAM OF PROCESS PLANNING

Prior to collecting the data, however, it was necessary to define certain terms so that a common basis could be formed for comparing the data. For the purposes of this analysis, the following definitions were used:

MACHINED PARTS: Machined parts are defined as those parts for which the primary manufacturing operations include milling, turning, boring, drilling, grinding, hobbing, etc. Machined parts do not include those parts for which the primary manufacturing operations are stamping, forming, welding, etc., nor does it include assemblies.

CYLINDRICAL MACHINED PARTS: Cylindrical machined parts are those for which the major features of the part are symmetrical about an axis of rotation and the primary manufacturing operations are turning, boring, etc. Examples of cylindrical machined parts include shafts, sleeves, pistons, etc.

NON-CYLINDRICAL MACHINED PARTS: Non-cylindrical machined parts are those for which the major features of the part are not symmetrical about an axis of rotation. Examples of non-cylindrical machined parts include engine blocks, pump housings, etc.

PROCESS PLANNING: Process planning is basically the conversion of part design information into the "how-to" information needed to manufacture the part. The inputs, outputs, and major functions of process planning are shown in Figure 1.

The process planner starts with information about the part design, the quantity of the part to be produced and the starting material the part will be made from. The process planner then performs the following types of tasks:

2.0 BENEFIT ANALYSIS

One of the major objectives of the basic program was to perform a cost benefit analysis on computerized production process planning (CPPP) for cylindrical and non-cylindrical machined parts. It has often been stated that computer aided manufacturing of which CPPP is a subset) is a field which intuitively "feels good" but is difficult to evaluate on an economic basis. We believe, however, that we have been successful in thoroughly evaluating the economics of CPPP, as well as identifying the intangible benefits to be gained through such systems.

In order to accomplish the cost benefit analysis, three major tasks had to be accomplished. First, data had to be collected which characterized the factors impacting the economic viability of CPPP, particularly with regard to Army Missile suppliers and other aerospace companies. Secondly, that data had to be compiled and analyzed in terms of its relevancy and validity. And lastly, a cost benefit analysis was performed using this information.

The methodology and results of each of these tasks is described in the following sections of the chapter, along with a section on conclusions from the analysis.

2.1 Data Collection

The purpose of this task was to obtain detailed information on the costs of manufacturing discrete machined parts, how these costs were related to the type of part being manufactured and the type of company, and the potential impact that various levels of process planning automation could have on these costs.

1.0 INTRODUCTION

The overall objective of this project was to perform a cost benefit analysis for various levels of computer aided process planning. In order to achieve this objective several tasks were undertaken:

1. Data was collected from various companies concerning the factors influencing the economic and non-economic aspects of computer aided process planning.

2. The data was compiled and analyzed to facilitate the cost benefit analysis and to identify the intangible benefits to be derived from computer aided process planning.

3. A computerized cost model was developed to perform the cost benefit analysis and 36 cases were analyzed using the model.

The next section presents an overview of the results, with more detailed information being provided in the appendices.

Because of the large amount of data received and analyzed, it would be impossible to summarize all the information in this section of the report. Therefore, only some of the more pertinent results will be presented here.

However before proceeding further, certain additional points should be made concerning the data and its analysis. First, no claim is made that the data represents a random sampling of the industry types analyzed; the individual addressees were not selected randomly, and, because of the nature of the data request, the majority of responses were from companies which have a sincere interest in the subject area. In addition, the number of responses was too small and incomplete to assign any meaningful degree of statistical confidence to the analysis.

Another point is that the individual responses to many questions varied widely. This can be attributed to many factors, such as: the size of the company and type of product; the current business trends the company was experiencing; a difference between respondees in their definition of process planning and machined parts; fundamental differences between companies in the depth of process planning performed, and, in some cases, lack of concrete data for which to use as a basis for the response.

Keeping these points in mind, some of the highlights of the data are presented below. The reader will perceive that, the above criticisms not withstanding, some interesting results were obtained.

2.2.1 Basic Data

Of the 21 companies responding, the value of products shipped annually ranged from $2 million to $800 million. All of the companies, with

the possible exception of one or two, are batch type manufacturers of discrete machined parts with varying degrees of product similarity within the company.

The average percent of products shipped (by dollar value) which represent cylindrical and non-cylindrical machined parts are as follows:

	Cyl.	Non-Cyl.
Missile Prime and Subcontractors	12.1%	10.3%
Other Aerospace Companies	11.1%	10.1%
Other Types of Manufacturers	21.8%	18.6%
All Responses	15.5%	13.4%

It can be concluded from the above that, in general, products of aerospace type companies (including Army missile suppliers) have a significant smaller percentage of the dollar value of their products representing machined parts than do other types of manufacturers. However, the spread on the responses to this question were large. For example, the responses from missile prime and subcontractors ranged from 5% to 25%, with a standard deviation of about 11%. Furthermore, it should be pointed out that aerospace products and machined parts are generally more expensive and, as will be seen later, their process planning costs are higher.

Each respondee was asked to estimate the dollar value of machined parts purchased from outside sources. Using these numbers in conjunction with other data contained in the survey, the approximate percentage of the dollar value of machined parts which are manufactured in-house can be estimated. The results were:

	Cyl.	Non-Cyl.
Missile Prime and Subcontractors	67%	72%
Other Aerospace Companies	93%	92%
Other Types of Manufacturers	62%	63%

We were unable to ascertain from the data whether or not the machined parts manufactured in-house by aerospace companies represented the more difficult parts to produce as opposed to the more easily manufactured parts. However based on the average piece part costs and process planning costs, we feel that the parts manufactured in-house by aerospace companies tend more towards the former case rather than the latter.

One of the questions in the data survey required a breakdown of the costs to manufacture a machined part in-house. The average of all responses is shown in Figures 2 and 3. It should be noted that the cost breakdowns for cylindrical and non-cylindrical machined parts is almost identical.

Several important observations were made during the analysis of the cost breakdowns. Although the numbers varied widely between respondees, some of the figures reported for overhead and profit appeared to be particularly unreasonable. Six of the responses were less than 12%. This may be due to a lack of access to such information or misinterpretation of the question.

Another observation concerning the cost breakdowns was that most respondees over-estimated the magnitude of their process planning costs in the breakdown. We were able to determine this by comparing the

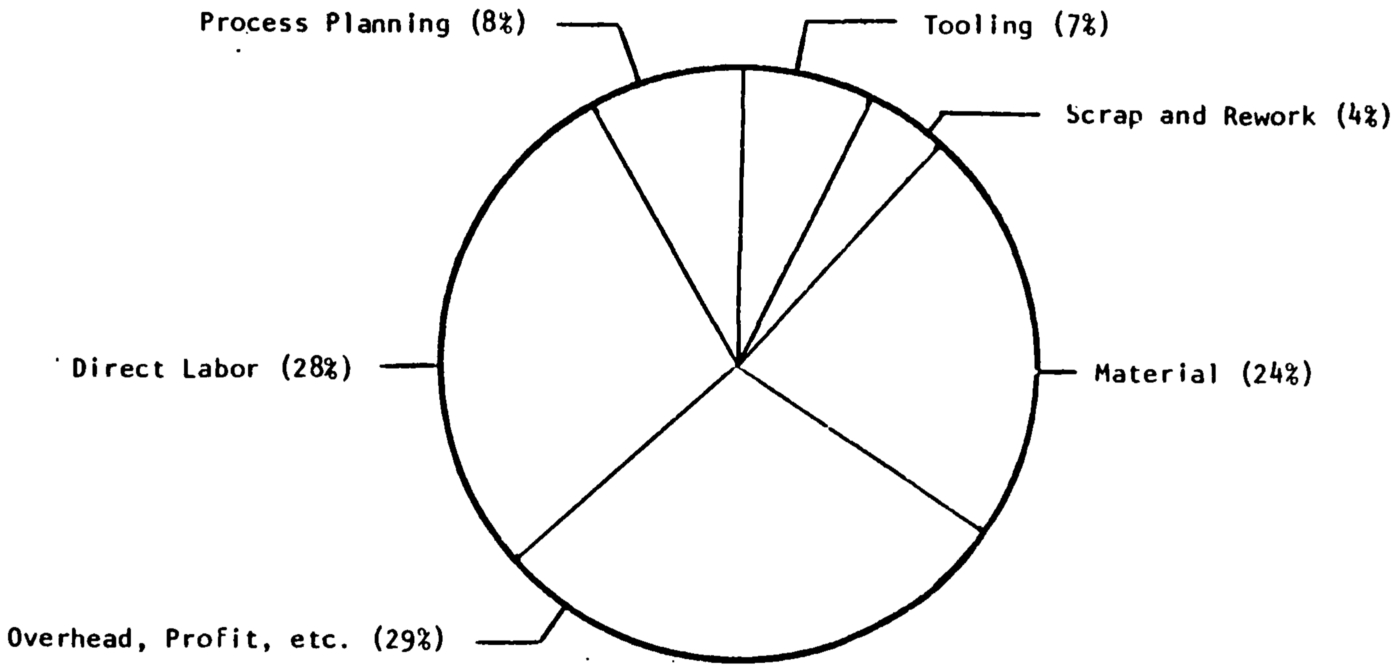


Figure 2. COST BREAKDOWN FOR NON-CYLINDRICAL MACHINED PARTS MANUFACTURED IN-HOUSE

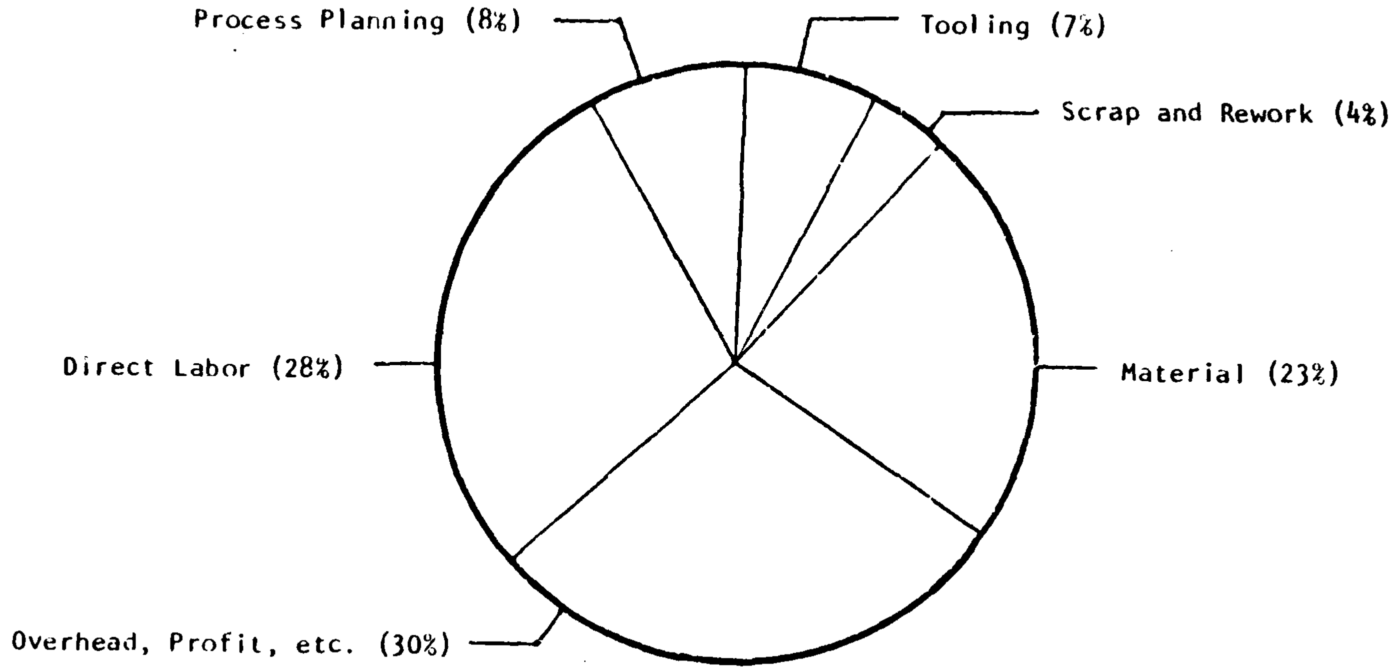


Figure 3. COST BREAKDOWN FOR CYLINDRICAL MACHINED PARTS MANUFACTURED IN-HOUSE

process planning costs from the breakdown to those derived from more detailed information on the number and types of plans prepared and their costs. The ratio of planning costs computed from the breakdown to planning costs derived from the detailed data ranged 0.02 to 125, with a mean of 22.3 for cylindrical parts and a mean of 10.3 for non-cylindrical parts. Therefore, it can be concluded that the process planning cost percentages shown in Figures 2 and 3 are overstated.

It was originally envisioned that data pertaining to batch size, number of batches per year, part similarity, and other factors indigenous to a particular company would be subjected to regression and correlation analyses to determine their relationship to process planning costs, etc. This was attempted on several variables and did not prove successful and was not carried further in light of time and funding limitations. However for the purposes of continuity of the report, a summary of the data on batch sizes and number of batches per year is presented in Tables 1 and 2.

The subject of part similarity was a major importance to the cost benefit analysis because any CPPP system must be based on part similarity within a company to be cost effective. To obtain information in this area, each addressee was requested to categorize the machined parts they manufacture in-house into three groups: 1) those that are basically similar and would have over 5 parts in a part family; 2) those that are somewhat similar and would have 2-5 parts per family; and 3) those that are totally different. A part family refers to the grouping of parts which are

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Batch Size	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
1 - 100	70%	72%	84%	92%	79%	64%	80%	76%
100 - 1000	30%	28%	14%	7%	14%	29%	16%	20%
Over 1000	<1%	<1%	2%	1%	6%	6%	4%	3%

(NOTE: All columns may not add to 100% because of averaging and rounding.)

TABLE 1. PERCENT OF CYLINDRICAL AND NON-CYLINDRICAL PARTS BY BATCH SIZE

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Batches/Year	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
1	37%	40%	6%	6%	16%	16%	15%	15%
2 - 10	63%	60%	67%	66%	61%	62%	63%	63%
Over 10	0%	0%	27%	39%	18%	18%	19%	20%

(NOTE: All columns may not add to 100% because of averaging and rounding.)

TABLE 2. PERCENT OF CYLINDRICAL AND NON-CYLINDRICAL PARTS BY NUMBER OF BATCHES PER YEAR

basically similar from the standpoint of design characteristics and the manufacturing processes required to produce the part. The average responses to this question is summarized in Table 3.

It can be noted from the table that aerospace companies did not indicate the degree of part similarity that other industry types did. However, two points should be kept in mind when considering the data. First, classification of parts into part families is very subjective and can be done from many different standpoints. Thus, this would be a particularly difficult question to answer with any degree of uniformity, especially if the respondees had not previously investigated their part similarity. Secondly, a lower degree of part similarity in and of itself does not necessarily imply that CPPP would not be cost effective for aerospace companies. This topic is discussed further in Section 2.3.

Information on the complexity of parts was also requested in the data survey. The criteria used for measuring part complexity was the number of operations contained on each process plan. Each respondee was asked to categorize the machined parts they manufacture in-house into three groups: 1) those having 1-10 operation per process plan; 2) those having 10-25 operations per plan; and 3) those having over 25 operations. The average responses are shown in Table 4. It can be seen that aerospace companies have a significantly greater number of operations per process plan than the other types of companies responding to the survey.

The respondees were also asked to estimate the cost, man-hours and leadtime to prepare a process plan for a new machined part as a function of the number of operations per plan. The average responses are contained

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Similarity	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Over 5 Parts Per Family	31%	31%	38%	15%	57%	48%	45%	32%
2-5 Parts Per Family	39%	37%	42%	44%	15%	27%	29%	35%
Totally Different	30%	32%	20%	41%	28%	25%	25%	33%

(NOTE: All columns may not add to 100% because of averaging and rounding.)

TABLE 3. PERCENT OF CYLINDRICAL AND NON-CYLINDRICAL PARTS BY PART SIMILARITY

Operations/ Plan	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
1 - 10	25%	23%	15%	17%	53%	59%	33%	35%
10 - 25	65%	67%	57%	49%	39%	30%	51%	44%
Over 25	10%	10%	28%	34%	8%	11%	17%	21%

(NOTE: All columns may not add to 100% because of averaging and rounding.)

TABLE 4 PERCENT OF CYLINDRICAL AND NON-CYLINDRICAL PARTS BY NUMBER OF OPERATIONS PER PROCESS PLAN

in Tables 5, 6, and 7. In each case, the values reported by aerospace companies were significantly larger than those for other industry types.

Generally speaking, process plans can be classified into one of three types: 1) plans prepared for a new part to be manufactured; 2) modification of an existing plan because of charges in part design or manufacturing techniques; or, 3) plans prepared for study purposes (e.g., cost estimates, design reviews, and make/buy analyses). The percent plans prepared in each of these categories is summarized in Table 8. It can be seen that in aerospace companies, more plans are modified and prepared for study purposes than in other types of industries. Also, the cost to prepare a typical process plan in each of these categories was also requested. The responses are shown in Table 9.

By taking the information mentioned in the previous paragraph, the percent of process planning costs attributable to each of the categories can then be calculated. The results of this calculation are illustrated in Table 10.

The final item to be discussed in this section is the relative breakdown within process planning costs. The averages of all responses is presented in Figures 4 and 5. There were no significant differences between breakdowns for cylindrical and non-cylindrical parts. The data indicates that the major cost drivers within process planning are: determining operation sequences, preparing operations sheets and selecting tooling and gages.

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Number of Operations	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
10	$ 123	$ 160	$ 231	$ 455	$ 78	$ 83	$144	$ 238
25	$ 525	$ 775	$ 658	$ 938	$159	$173	$407	$ 560
50	$1225	$1850	$1320	$2221	$409	$439	$887	$1344

TABLE 5. COST TO PREPARE A PROCESS PLAN FOR CYLINDRICAL AND NON-CYLINDRICAL PARTS BY NUMBER OF OPERATIONS PLAN PLAN

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Number of Operations	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
10	11 M-H	19 M-H	20 M-H	20 M-H	4 M-H	4 M-H	11 M-H	17 M-H
25	33 M-H	55 M-H	45 M-H	67 M-H	8 M-H	8 M-H	26 M-H	39 M-H
50	55 M-H	75 M-H	97 M-H	157 M-H	21 M-H	23 M-H	58 M-H	87 M-H

TABLE 6. MAN-HOURS TO PREPARE A PROCESS FOR CYLINDRICAL AND NON-CYLINDRICAL PARTS BY NUMBER OF OPERATIONS PER PLAN

Planning Function	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Determine Opn. Sequences	40%	41%	12%	8%	55%	53%	36%	36%
Machine Selection	58%	58%	10%	7%	33%	31%	27%	27%
Tool Selection	31%	32%	12%	9%	37%	34%	26%	25%
Determine Process Parameters	31%	32%	20%	18%	33%	32%	27%	27%
Time Stds	32%	32%	6%	8%	31%	29%	22%	23%
Tolerance Analysis	46%	46%	7%	6%	15%	14%	16%	16%
Documentation	25%	28%	15%	14%	36%	34%	32%	27%

Table 15. PERCENT COST REDUCTION IN PROCESS PLANNING FUNCTIONS RESULTING FROM SYSTEM 2

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Cost Area	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Process Planning	27%	30%	31%	31%	52%	50%	39%	39%
Material	4%	4%	1%	1%	4%	4%	3%	3%
Direct Labor	7%	7%	8%	6%	7%	6%	7%	6%
Scrap & Rework	12%	12%	4%	3%	5%	5%	6%	6%
Tooling	10%	10%	4%	3%	8%	8%	7%	7%
WIPI	3%	3%	1%	1%	7%	7%	4%	4%

Table 14. PERCENT COST REDUCTIONS RESULTING FROM SYSTEM 2

The benefits and costs are summarized in Tables 14, 15 and 16. As was the case with System 1, the non-aerospace companies estimated significantly higher benefits to be derived from System 2 than did the aerospace companies.

The obstacles to implementing System 2 which cited by the respondees were essentially the same as those for System 1, but with the addition of the following:

- The need for large direct access memories.
- Lack of efficient data base management techniques.
- Because of the large investment required, implementation would need to be time phased with a new major product introduction.
- Resistance on the part of the process planners to use CRT terminals.

2.2.4 System 3 Data

System 3 was the highest level of process planning automation described in the data survey and is the one that most closely resembles the system being developed by the Army. It has all of the capabilities of System 2 plus the ability to generate the optimize process plans using internally stored decision logic and data.

The respondees estimates of the benefits and costs of System 3 over manual process planning are shown in Tables 17, 18 and 19. There appears to be more uniformity between industry types concerning the benefits to be derived from System 3 than for either of the two other systems.

Some of the major obstacles to implementing System 1 which were mentioned by the respondees were:

- Economic justification.
- Interfacing existing systems and related hardware.
- Getting the system debugged and operational.
- Training of personnel.
- Developing and assigning the group technology codes.
- Lack of qualified computer analysts to maintain the system.
- Insuring quality of input data.
- Lack of management commitment.
- Inability of the system to take into consideration such factors as machine loading, alternate work flows and effective material handling.
- Getting user acceptance for the system.
- Factory re-arrangement as a result of group technology approach.

2.2.3 System 2 Data

System 2 was the second hypothetical level of process planning automation described in the data request. It can do everything System 1 can, but has additional capabilities for interactive process planning using the variant approach and computer aided cutting parameter determination.

As was done for the previous sytem, each respondee was asked to estimate the benefits and costs for System 2 over manual process planning and to list the major obstacles to implementation within their plant.

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Cost Areas	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Hardware	$76K	$76K	$10K	$ 0	$ 0	$ 0	$40K	$ 38K
Establish Data Files	$33K	$39K	$14K	$ 8K	$75K	$1425K	$40K	$496K
Training	$ 8K	$ 9K	$ 4K	$17K	$ 1K	$ 2K	$ 5K	$ 9K
Test System	$ 9K	$10K	$ 6K	$13K	$ 3K	$ 3K	$ 6K	$ 9K
Computer Chgs. & Prog. Maint/Year	$22K	$26K	$34K	$93K	$17K	$ 20K	$26K	$ 52K
Update Data Files/Year	$ 7K	$ 9K	$24K	$85K	$ 5K	$ 5K	$13K	$ 40K

Table 13. IMPLEMENTATION AND RECURRING COSTS FOR SYSTEM 1

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Planning Function	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Determine Opn Sequences	21%	21%	9%	7%	45%	43%	26%	25%
Machine Selection	26%	21%	5%	4%	23%	21%	15%	15%
Tool Selection	24%	24%	4%	4%	18%	15%	14%	13%
Determine Process Parameters	16%	16%	12%	12%	15%	14%	14%	14%
Time Stds	21%	21%	6%	8%	20%	18%	15%	15%
Tolerence Analysis	24%	24%	<1%	8%	7%	7%	8%	8%
Documentation	9%	9%	9%	7%	27%	25%	16%	15%

Table 12. PERCENT COST REDUCTION IN PROCESS PLANNING FUNCTIONS RESULTING FROM SYSTEM 1

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Cost Area	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Process Planning	14%	14%	23%	20%	40%	38%	28%	26%
Material	3%	3%	<1%	<1%	5%	5%	3%	3%
Direct Labor	5%	5%	3%	4%	6%	6%	5%	5%
Scrap & Rework	8%	8%	1%	1%	4%	4%	4%	4%
Tooling	1%	7%	3%	3%	6%	6%	5%	5%
WIPI	1%	1%	<1%	<1%	5%	5%	2%	3%

Table 11. PERCENT COST REDUCTIONS RESULTING FROM SYSTEM 1

Only some of the highlights of the basic data were presented in this section. The reader should refer to Appendices B and C for additional information.

The next section discusses the responses received pertaining to System 1.

2.2.2 System 1 Data

System 1 was the first of three levels of process planning automation described in the data request. It is a relatively simple system based on the concept of group technology as a means of identifying currently existing process plans for similar parts which would then be used as a starting point for preparing a new process plan. Also, the operation and routing sheet information would be placed on coded forms and then keypunched for computerized generation of shop floor paper.

Each respondee was asked to estimate the change in process planning costs System 1 would provide over manual process planning techniques and the cost of implementing and maintaining such a system in their plant. Additionally, they were asked to identify major obstacles to implementing the system.

A summary of the responses is contained in Tables 11, 12 and 13. There was a wide range on the estimates received and there was no apparent trends in terms of benefits to be gained from System 1, with the exception that the other industry category estimated significantly higher cost savings in process planning costs.

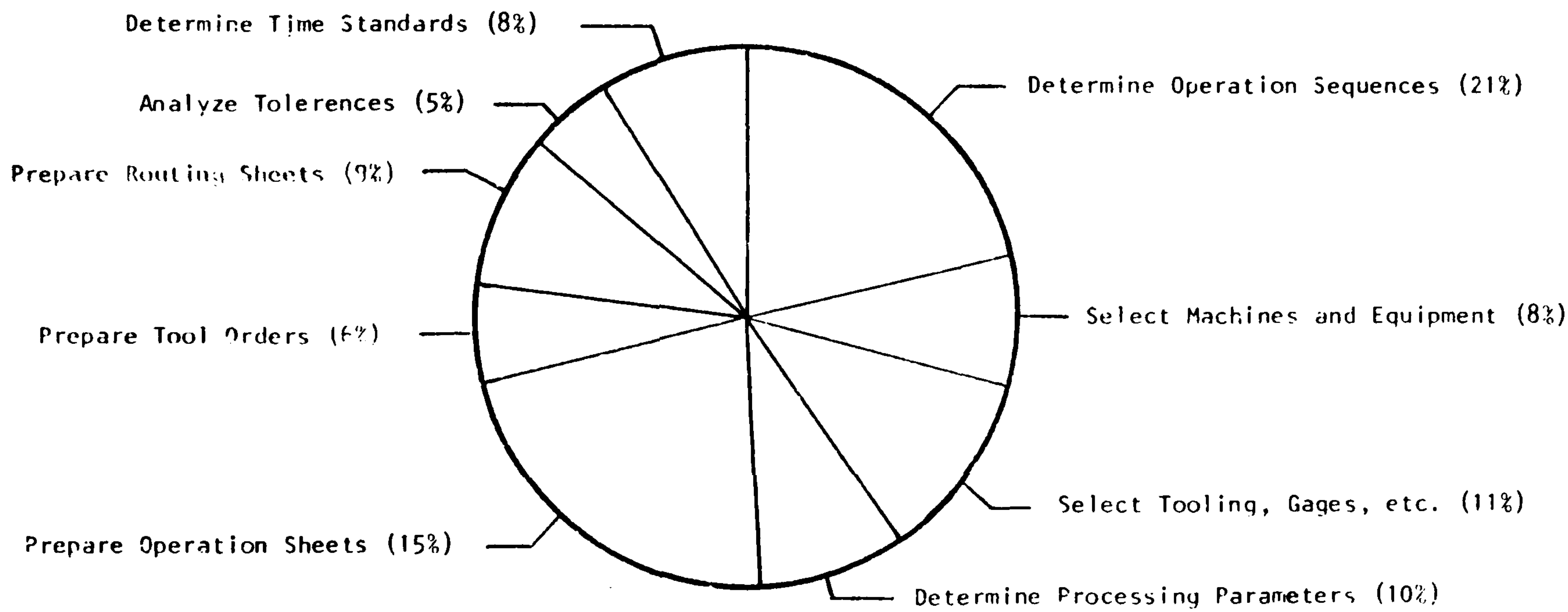


Figure 5. COST BREAKDOWN FOR PREPARING A PROCESS PLANN FOR A NEW NON-CYLINDRICAL MACHINED PART

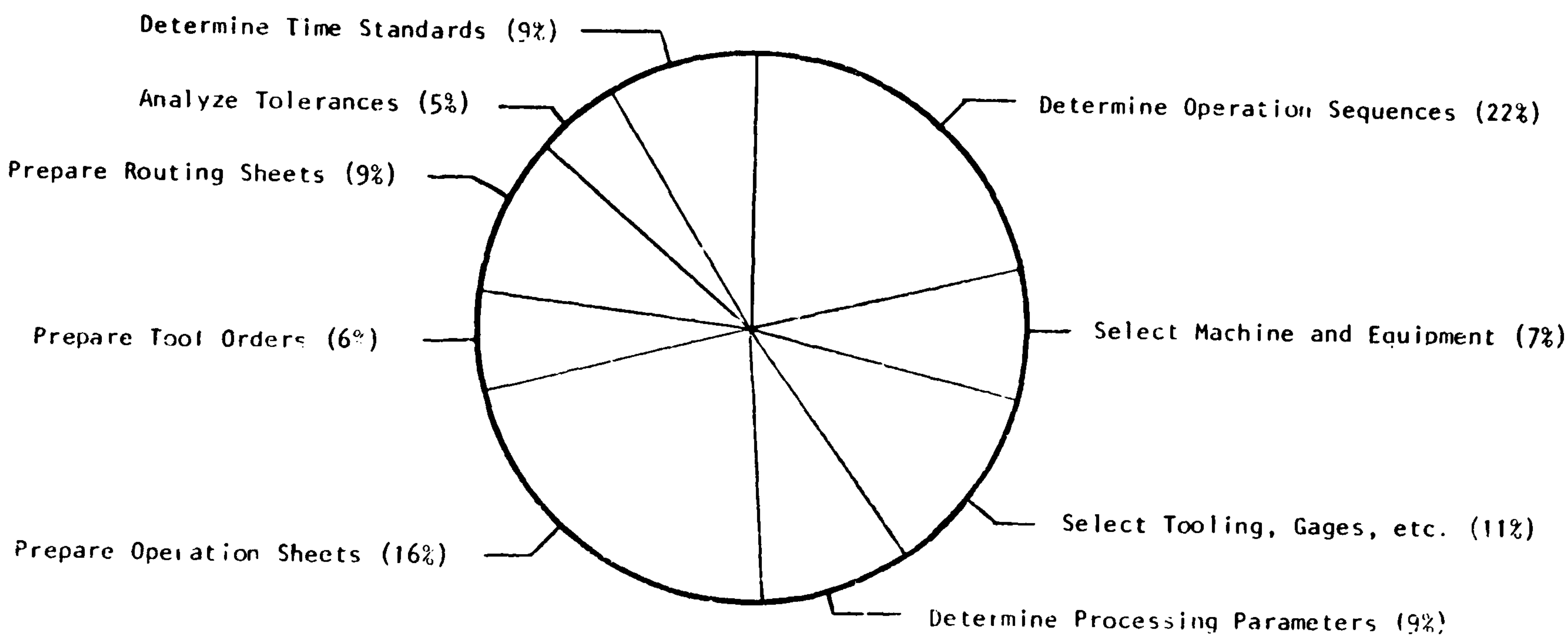


Figure 4. COST BREAKDOWN FOR PREPARING A PROCESS PLAN FOR A NEW CYLINDRICAL MACHINED PART

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Type of Plan	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Plan for new part	62%	54%	42%	39%	69%	62%	57%	53%
Modify Plan existing part	19%	26%	38%	42%	26%	33%	28%	35%
Plan for Studies	19%	20%	20%	19%	5%	5%	13%	13%

(NOTE: All columns may not add to 100% because of averaging and rounding.)

TABLE 10. PERCENT OF PROCESS PLANNING COSTS FOR CYLINDRICAL AND NON-CYLINDRICAL PARTS BY TYPE OF PLAN

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Type of Plan	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Plan for new part	$330	$547	$760	$1366	$398	$399	$492	$709
Modify Plan for existing part	$112	$170	$228	$ 217	$149	$149	$166	$173
Plan for Studies	$ 81	$118	$194	$ 157	$ 89	$ 87	$124	$117

TABLE 9. COST TO PREPARE A PROCESS PLAN FOR CYLINDRICAL AND NON-CYLINDRICAL PARTS BY TYPE OF PLAN

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Type of Plan	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Plan for new part	33%	29%	28%	23%	56%	51%	39%	35%
Modify plan for existing part	22%	28%	51%	56%	36%	42%	39%	45%
Plan for Studies	45%	44%	22%	21%	7%	7%	21%	21%

(NOTE: All columns may not add to 100% because of averaging and rounding.)

TABLE 8. PERCENT OF PROCESS PLANS PREPARED FOR CYLINDRICAL AND NON-CYLINDRICAL PARTS BY TYPE OF PLAN

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Number of Operations	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
10	14 days	22 days	14 days	17 days	7 days	7 days	11 days	14 days
25	23 days	35 days	20 days	29 days	10 days	10 days	17 days	23 days
50	23 days	27 days	30 days	44 days	18 days	18 days	24 days	30 days

TABLE 7. LEADTIME TO PREPARE A PROCESS PLAN FOR CYLINDRICAL AND NON-CYLINDRICAL PARTS BY NUMBER OF OPERATIONS PER PLAN

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Cost Area	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Hardware	$100K	$102K	$56K	$100K	$194K	$ 77K	$117K	$ 91K
Establish Data Files	$ 33K	$ 36K	$44K	$ 88K	$232K	$119K	$119K	$ 88K
Training	$ 9K	$ 10K	$10K	$ 11K	$ 14K	$ 10K	$ 11K	$ 10K
Test System	$ 11K	$ 15K	$13K	$ 21K	$ 25K	$ 19K	$ 18K	$ 18K
Computer Chgs. & Prog. Maint/Year	$ 38K	$ 50K	$24K	$ 44K	$ 29K	$ 19K	$ 29K	$ 36K
Update Data Files/Year	$ 11K	$ 14K	$18K	$ 21K	$ 46K	$ 16K	$ 27K	$ 17K

Table 16. IMPLEMENTATION AND RECURRING COSTS FOR SYSTEM 2

	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
Cost Area	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Process Planning	45%	45%	65%	60%	58%	57%	58%	56%
Material	4%	4%	2%	2%	7%	7%	4%	4%
Direct Labor	10%	10%	10%	9%	10%	10%	10%	10%
Scrap & Rework	15%	15%	7%	6%	11%	11%	10%	10%
Tooling	13%	13%	9%	7%	18%	18%	12%	12%
WIPI	9%	9%	1%	1%	10%	10%	6%	7%

Table 17. PERCENT COST REDUCTIONS RESULTING FROM SYSTEM 3

Planning Function	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Determine Opn. Sequences	49%	49%	36%	29%	64%	63%	51%	49%
Machine Selection	43%	43%	29%	16%	45%	44%	39%	35%
Tool Selection	36%	36%	35%	29%	41%	41%	38%	36%
Determine Process Parameters	44%	48%	33%	24%	41%	40%	39%	36%
Time Stds.	38%	38%	33%	34%	49%	49%	41%	41%
Tolerance Analysis	36%	36%	25%	13%	22%	14%	26%	19%
Documentation	45%	45%	48%	40%	59%	[illegible]	52%	50%

Table 18. PRESENT COST REDUCTION IN PROCESS PLANNING FUNCTIONS RESULTING FROM SYSTEM [illegible]

Cost Area	Missile Primes and Subs		Other Aerospace		Other Industry		All Responses	
	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl	Cyl	Non-Cyl
Hardware	$178K	$203K	$82K	$190K	$377K	$137K	$224K	$174K
Establish Data Files	$109K	$189K	$53K	$129K	$626K	$290K	$314K	$204K
Training	$ 22K	$ 32K	$10K	$ 20K	$ 25K	$ 18K	$ 19K	$ 22K
Test System	$ 28K	$ 44K	$15K	$ 42K	$ 54K	$318K	$ 34K	$ 38K
Compute Chgs. & Prog. Main/ Year	$ 50K	$ 67K	$43K	$115K	$ 78K	$ 57K	$ 57K	$ 83K
Update Data Files/Year	$ 18K	$ 24K	$34K	$ 40K	$ 81K	$ 49K	$ 46K	$ 39K

Table 19. IMPLEMENTATION AND RECURRING COSTS FOR SYSTEM 3

The factors listed as obstacles to implementing System 3 were the same as those for Systems 1 and 2, but with the following additions:

- Major problems would exist in developing effective decision rules that allow manufacturing efficiency and at the same time would not be too complex or costly to develop.
- Developing decision rules for planning complex parts.
- Establishing initial data bases for machines, equipment, tooling, etc.
- Maintenance of the data base
- System complexity, reliability and risk.
- Possibly exceeding the state-of-the-art.
- May not be user oriented enough.

2.2.5 Comparison of Systems 1, 2 and 3

This section presents a summarization and distillation of the data on Systems 1, 2 and 3 for the purpose of more easily comparing the costs and benefits of each system.

The net impact of Systems 1, 2 and 3 on the cost of manufacturing cylindrical machined parts is shown in Table 20. Cylindrical parts were picked as the basis for comparison because that is the type of system the Army is developing. The table is a consolidation of all the responses and represents the estimated cost reductions possible for each system.

Cost Area	System 1	System 2	System 3
Process Planning	-2.24%	-3.12%	-4.64%
Material	-0.69%	-0.69%	-0.92%
Direct Labor	-0.84%	-1.96%	-2.80%
Scrap and Rework	-0.16%	-0.24%	-0.40%
Tooling	-0.35%	-0.49%	-0.84%
Totals	-4.28%	-6.50%	-9.60%

TABLE 20. Impact of Systems 1, 2 and 3 on Cost of Cylindrical Machined Parts (Excluding Influence of Overhead, Profit, etc.).

The implementation costs and recurring annual costs for each system is shown in Table 21. Again, this is an average of all the responses received.

By comparing Tables 21 and 22, the economic advantages and disadvantages of each of the systems is quite obvious. However, the systems should not be prejudged on this data alone; an economic analysis of each of the systems which further explores this issue is contained in Section 2.3.

However before turning to the economic analysis, certain intangible benefits should be considered for each of the systems. The data survey contained a list of areas which are somewhat intangible in nature and which could be impacted by CPPP. The respondees were asked to rank the impacts of Systems 1, 2 and 3 on each of the areas using a scale of -2 to +2, where: -2 = significantly negative impact; -1 = somewhat negative impact; 0 = no impact; +1 = somewhat positive impact; and +2 = significantly positive impact. These rankings were then averaged to yield a relative scale of impacts on each area for each system. The results are presented in Table 22.

It was suprising to note that CPPP had a positive impact on each area listed. Even more important, however, are the significant increases in impact as the level of process planning automation increases.

One final point should be made concerning the data analysis, and that is the receptivity of industry to process planning automation. To determine this, the data survey contained a question on current and

Cost Area	System 1	System 2	System 3
Implementation Costs			
Hardware	$40K	$117K	$224K
Establish Data Files	40K	119K	314K
Train Personnel	5K	11K	19K
Test System	6K	18K	34K
Totals	$91K	$265K	$591K
Recurring Cost (per year)			
Computer Charges and Program Maintenance	$26K	$29K	$57K
Updating Data Files	13K	27K	46K
	$39K	$56K	$103K

TABLE 21 . Implementation and Recurring Costs for Systems 1, 2 and 3 for Cylindrical Machined Parts.

AREAS IMPACTED	System 1	System 2	System 3
PRODUCTION LEADTIME	0.86	1.30	1.47
PROCESS PLANNING LEADTIME	1.24	1.55	1.89
MACHINE UTILIZATION	0.57	0.85	1.41
PRODUCT QUALITY	0.38	0.45	0.79
DIRECT LABOR UTILIZATION	0.48	0.45	1.00
UNIFORMITY OF PROCESS PLANS	1.48	1.70	1.89
COST ESTIMATING PROCEDURES	1.14	1.32	1.79
MAKE/BUY DECISIONS	0.76	1.56	1.33
PRODUCT STANDARDIZATION	0.81	1.16	1.33
CRITICAL LABOR SKILLS	0.29	0.37	0.78
MATERIAL STANDARDIZATION	0.57	0.68	0.89
PRODUCIBILITY OF PARTS	0.55	0.65	1.11
PLANT LAYOUT	0.43	0.65	0.84
MATERIAL HANDLING	0.62	0.79	1.06
PRODUCTION SCHEDULING	0.80	0.95	1.37
CAPACITY PLANNING	0.80	1.00	1.37

(RANKED ON A SCALE OF -2 TO +2, WHERE -2 = SIGNIFICANTLY NEGATIVE IMPACT, 0 = NO CHANGE, +2 = SIGNIFICANT IMPROVEMENT)

Table 22. IMPACT OF SYSTEMS 1, 2, AND 3 ON OTHER AREAS

planned (within 2 years) usage of some form of automated process planning techniques. Twenty companies, or an equivalent of 95% of the respondees indicated that they are either currently using, or plan to use some form of computer aided process planning.

2.3 Cost Benefit Analysis

This section briefly describes the cost benefit analysis which was performed during the program. It contains a discussion of the methodology used, the results and conclusions which can be drawn from those results.

2.3.1 Methodology

The methodology used to conduct the cost benefit analysis was to construct a computerized cost model which would accept data on various cases consisting of CPPP systems and manufacturing situations and then perform a detailed economic analysis for each case. The computer program would calculate the cash flows involved and would calculate benefit-to-cost ratios (BCR), years to payback (YTP) and return on investment (ROI), both before and after taxes. Also, the computer program would perform a sensitivity analysis on 17 different input variables to determine the effect each had on BCR, YTP and ROI. The specifics of the methodology are contained in Appendix D.

Inputs to the cost model were:

- Annual value of parts manufactured.
- Annual value of work-in-process inventory (WIPI).

- A percentage cost breakdown for the parts in terms of; a) process planning; b) tooling; c) direct labor; d) material; e) scrap and rework; and, f) overhead, profit, etc.
- Percentage of potential savings as a result of the CPPP system in: a) process planning; b) tooling; c) direct labor; d) material, e) scrap and rework; and f) WIPI.
- Hardware costs by year.
- Cost to establish initial data files by year.
- Cost to train personnel by year.
- Computer charges and program maintenance by year.
- Cost to update data files by year.
- Percentage of Parts Impacted (PPI) (by dollar value) by year.

Using this information, the computer program then computed the annual cash flows for 14 factors, including such items as: process planning savings; direct labor savings; savings due to reductions in WIPI; depreciation; and, investment tax credit.

The cost model considered a ten year period and computer the cumulative present value of the cash flow, the BCR and the YTP assuming an interest rate of 10% per year. A sum-of-the-years-digits methods of depreciation was used and a 7% investment tax credit was assumed. A corporate income tax rate of 48% was also used in the calculations.

The sensitivity analysis consisted of changing the original input values ±10% and then calculating the net change in BCR, YTP and ROI after taxes and depreciation. This provided the ability to identify those factors which have the greatest impact on economic viability of the case in question.

The physical output from the computer program consists of three pages. The first is a printout of the input data, case number and title. The second is a printout of the detailed cash flows by year and the BCR, YTP and ROI, both before and after taxes. The third page contains a printout of the sensitivity analysis.

Thirty-six cases were constructed and run through the computer program. The first six cases were essentially the composite data resulting from the information derived from the data analysis mentioned previously. The number of cases for the composite data was derived by multiplying the number of part types (2) (i.e., cylindrical and non-cylindrical) times the number of different CPPP systems (3) (i.e., Systems 1, 2 and 3).

In addition to the composite data, it became apparent during the data analysis that at least three distinct types of manufacturing situations could be identified and quantified for cost benefit analysis. They differ primarily in the dollar volume of parts manufactured, the degree of part similarity as reflected in the steady-state PPI values, and the distribution of the percentages within the cost breakdown.

The first type of manufacturing situation is what we have identified, for lack of a better term, as a Medium Size/Similar Parts manufacturer.

This type of manufacturer is characterized as having an annual volume of business of $10 million in machined parts of each type and a product mix such that ultimately about 70% of their cylindrical and 60% of their non-cylindrical parts of dollar volume will receive the full benefits of the CPPP systems. Also, this type of manufacturer has a somewhat higher overhead rate and percentage of process planning costs than the other two manufacturing situations described later.

It should be pointed out that the intent here is not to stereotype certain types of companies or industries, but rather to describe manufacturing situations to which many different types of companies could relate. For example, the Medium Size/Similar Parts manufacturer mentioned above could correspond to the parts manufacturing situation of a large aerospace prime contractor or a company manufacturing large power generation equipment. On the other hand, these or similar companies could have a parts manufacturing situation more closely related to one of the other situations described below.

As with the composite data, six cases were constructed and run for the Medium Size/Similar Parts manufacturer.

The second type of manufacturing situation that was defined has been identified as a Large Size/Highly Similar Parts manufacturer. This type of manufacturer is characterized as having an annual volume of business of $50 million in machined parts of each type and a product mix such that ultimately about 90% of their parts by dollar volume will receive the full benefits of the CPPP systems. This type of manufacturer has a somewhat

lower overhead rate and percentage of process planning costs than the Medium Size/Similar Parts manufacturer. Six cases were also constructed and run for the Large Size/Highly Similar Parts manufacturer.

The third type of manufacturing situation has been named the Small Size/Highly Similar Parts manufacturer. It is essentially the same as the Large Size/Highly Similar Parts manufacturer except that its annual business volume is $5 million in machined parts of each type. Like the other manufacturing types, six cases (2 part types times 3 CPPP Systems) were constructed and run for the Small Size/Highly Similar Parts manufacturer.

In constructing the input data, every effort was made to be objective and reasonable in determining the numbers in light of the data received and our knowledge of the subject matter. However, it became apparent that two types of input data needed for the cost model would require a certain degree of subjective judgment to come with the values. The two inputs in question are the Percentage of Parts Impacted (PPI) (by dollar volume) by year and the percentage of cost attributable to overhead and profit which is fixed and not variable, and therefore would not contribute to the cost savings obtainable through the application of a particular CPPP system.

As far as the PPI by year is concerned, it was derived by estimating the capability of a system to provide process planning coverage and this capability was then multiplied by the ratio of new and modified plans prepared to the total number of different parts manufactured annually, thereby

resulting in the PPI during a particular year. However, this is a cumulative process and the PPI continues to build up until a steady-state value is reached which is equivalent to the capability of the system. In other words, for any given year the system would only impact those parts for which new or modified process plans were prepared in addition to those processed through the system in prior years.

A simple example might help to illustrate the point. Assume that the process planning system was only capable of impacting 50% of the parts manufactured during the first year and 100% of the parts manufactured during the second and subsequent years. However, not all the benefits of the system will be achieved unless all of the parts are planned each year. Therefore, let us assume that 10% of the parts that are manufactured annually are either planned or replanned each year. Then the PPI would be calculated as follows.

Year	System Capability	% of Parts Planned/Year	PPI
1	50%	10%	5%
2	100%	10%	10% + 5% = 15%
3	100%	10%	10% + 15% = 25%
.			
.			
.			
Steady-State	100%		100%

Because of the subject nature in deriving estimates for PPI by year, both IITRI and UTRC independently came up with estimates for the values. IITRI's PPI values were used in the first 24 cases and UTRC's values were used in cases 25 through 36.

As far as the overhead issue is concerned, we were not able to rationalize the relationship between fixed and variable overhead rates and how they interact with other cost breakdown factors such as process planning and direct labor. It is not clear that reducing the costs of manufacturing machined parts will reduce the overhead rate. Some might argue that the overhead rate might even increase. However, because overhead and profit represent such a substantial portion of the costs to produce machined parts and some of the overhead on direct labor, tooling, material, etc. must be variable, it was decided to reduce the original overhead percentages by several points and distribute them about proportionally to the other cost areas.

Certain underlying assumptions were made concerning the cost benefit analysis:

1) no software development costs were included -- the analysis was done from the standpoint that the software would be provided free of charge to the companies; 2) the only hardware costs would be for CRT terminals, printers and interfacing equipment--it was assumed that the companies would either have sufficient computer resources available either in-house or through bureau services; and 3) the potential

cost reductions for each of the 3 CPPP systems were about the same as those resulting from the data analysis.

Appendix E contains the complete inputs and outputs for each of the 36 cases. The results of the cost benefit analyses are summarized in the following section.

2.3.2 Results of the Cost Benefit Analyses

The results of the cost benefit analyses are summarized in Table 23. Each case is identified by a case number corresponding to those in Appendix E. In addition, each case is characterized by the type of manufacturer, the type of machined part and the type of hypothetical process planning system involved.

Table 23 also contains the benefit-to-cost ratio, the years to payback and the return on investment after taxes and depreciation, as well as the cumulative present value of the cash flow at the end of year 10.

An examination of Table 23 will show that System 1 consistently ranked higher in all economic indicators except the cumulative present value of the cash flow at the end of year 10. What this means is that although System 1 has a better short term economic advantage, in the long term, Systems 2 and 3 will return greater economic benefits. Plots of the cumulative present value of the cash flow by year are contained in Appendix F.

Case #	Type of Manufacturer	Part Type	System	BCR	YTP	ROI(%)	CPV @ YR 10 ($K)
1	Composite Data	Cyl	1	10.69	2.1	196.1	1625
2	"	"	2	7.75	2.5	122.5	2251
3	"	"	3	5.86	2.9	101.4	3191
4	"	Non-Cyl	1	3.04	4.0	51.7	951
5	"	"	2	6.72	2.5	120.1	1616
6	"	"	3	4.88	2.9	102.5	2361
7	Medium Size (Similar Parts)	Cyl	1	4.63	3.0	104.7	388
8	"	"	2	2.41	4.2	62.8	447
9	"	"	3	1.71	5.5	37.9	427
10	"	Non-Cyl	1	4.51	2.8	109.2	375
11	"	"	2	2.31	4.1	61.1	428
12	"	"	3	1.49	6.1	28.8	345
13	Large Size (Highly Similar Parts)	Cyl	1	13.47	1.8	263.7	2464
14	"	"	2	8.47	2.3	193.3	3429
15	"	"	3	5.86	3.2	126.5	4200
16	"	Non-Cyl	1	13.91	1.9	241.2	2700
17	"	"	2	9.24	2.2	201.8	3862

TABLE 23. Summary of Economic Analysis Results

Case #	Type of Manufacturer	Part Type	System	BCR	YTP	ROI(%)	CPV @ YR 10 ($K)
18	"	"	3	5.83	3.4	[illegible]09.6	[illegible]837
19	Small Size (Highly Similar Parts)	Cyl	1	7.53	2.5	134.9	254
20	"	"	2	3.43	4.1	61.5	315
21	"	"	3	1.91	5.7	38.2	283
22	"	Non-Cyl	1	7.48	2.6	124.4	269
23	"	"	2	3.41	4.2	59.4	336
24	"	"	3	1.70	6.3	29.9	263
25	Case 1 w/UTRC PPI	Cyl	1	11.12	2.1	197.7	1698
26	Case 2 w/UTRC PPI	"	2	8.06	2.5	123.9	2354
27	Case 3 w/PPI	"	3	5.57	3.2	88.9	3001
28	Case 7 w/UTRC PPI	"	1	5.43	2.6	125.5	474
29	Case 8 w/UTRC PPI	"	2	2.82	3.6	77.6	576
30	Case 9 w/UTRC PPI	"	3	1.92	5.0	46.2	549
31	Case 13 w/UTRC PPI	"	1	15.49	2.0	317.4	2887
32	Case 14 w/UTRC PPI	"	2	9.73	2.2	242.8	4008
33	Case 15 w/UTRC PPI	"	3	6.70	2.7	171.[illegible]	4927
34	Case 19 w/UTRC PPI	"	1	8.66	2.3	168.0	299

TABLE 23. Summary of Economic Analysis Results (continued)

Case #	Type of Manufacturer	Part Type	System	BCR	YTP	ROI (%)	CPV @ YR 10 ($K)
35	Case 20 w/UTRC PPI	"	2	3.93	3.4	76.6	380
36	Case 21 w/UTRC PPI	"	3	2.18	4.5	50.2	366

TABLE 23. Summary of Economic Analysis Results (continued)

The sensitivity analyses indicated that the following are the most important factors influencing the economic impacts of the case studies, although their order of importance may vary from case to case.

- Percent of Parts impacted (by dollar value) per year.
- The value of the machined parts being produced.
- Implementation costs.
- The percentage of costs attributable to overhead and profit.

2.3.3 Conclusions

Using the information derived from the data analysis and the assumptions stated in the previous section, each of the 36 cases analyzed resulted in positive economic indicators. However, System 1 quite clearly showed the best short term performance, while Systems 2 and 3 would provide significant economic advantages over System 1 in the long term.

The factors influencing the economics of computerized process planning are numerous, but the most significant are the dollar value of parts being manufactured, the percentage of that value which can be impacted by the CPPP system and the implementation costs for the system. It is difficult to generalize on the interaction of the factors as they apply to System 3, but there is an apparent lower limit below which System 3 is no long economically viable (i.e., a benefit-to-cost ratio of less than 1). That limit, in terms of dollar value of highly similar parts produced

annually is approximately $3 million.

However, Section 3 is economically viable for large parts manufacturers and does offer significant advantages over Systems 1 and 2 in terms of intangible benefits. Also, System 3 offers future growth potential in increasing overall manufacturing productivity by ultimately linking process planning with other functions such as production planning and control and design engineering.

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